

APPENDIX A – DESCRIPTION OF REMEDIATION TECHNOLOGIES FOR SOIL

A.1 Introduction

This appendix describes the remediation technologies and corresponding process options associated with each general response action listed in Section 4.3. The information in this appendix forms the basis for the screening of the technologies presented in Tables 4-1 and 4-2. The general response actions, technologies, and process options are organized in this appendix in the same order they are arranged on the tables.

The general response actions identified for the remediation of metals- impacted soils at the Former DuPont Works Site (Site) include:

- No Action;
- Institutional controls;
- Containment;
- Removal;
- Treatment; and
- Stabilization.

The technology performance is compared with the chemical concentrations observed at the Site and the remediation or cleanup level considered appropriate for the land use are presented on the figures. All the technologies are able to meet the RAOs.

A.2 No Action

The No Action alternative is retained throughout the feasibility study process. It provides a baseline to compare the other alternatives to evaluate their effectiveness. The no action response literally means leaving the Site exactly as it exists at the time of preparation of the FS.

A.3 Institutional Controls

Institutional Controls are physical or legal restrictions used to prevent exposure to Site constituents. Typically, exposure is prevented or reduced by restricting access to the Site or to potential constituent receptors—such as groundwater or wildlife. The toxicity, volume, and mobility of the constituents are not reduced.

For these restrictions to be effective, they require understanding and compliance by the population being protected. Two types of institutional controls (technologies)—access restrictions and monitoring—are described below.

A.3.1 Access Restriction

Access restriction falls into two basic types: physical restrictions and legal restrictions. The physical restrictions are usually easy to implement and very cost-effective. The legal restrictions are also easy to implement and restrict future use of the property.

Fence: Fencing a site is an inexpensive and effective method for restricting access. Simple fences (such as chain-link) accomplish significant reduction of potential human exposure. If required, special fences

can be constructed to keep out wildlife. Fencing does not prevent access to small burrowing animals or birds. Well-constructed fences may last many years with little maintenance. Since the Site will be developed as recreational, commercial, and industrial areas, fences will have little applicability. They are currently used to restrict access to the Site during the RI and interim source removal and will continue to be used during future cleanup actions.

Warning Signs: Warning signs are also very effective at restricting access at very little cost. They are most effective when used with fencing. Since the Site will be developed as recreational, commercial, and industrial areas, warning signs will have little applicability. They are currently used to restrict access to the Site during ongoing activities.

Deed Restrictions: Deed restrictions may be useful in preventing accidental exposure due to activities of future property owners. The deed restriction notifies future owners of specific Site conditions to prevent activities that may release constituents or increase exposure. Generally, Site-wide deed restrictions would reduce the value of the Site.

Fishing/Hunting Restrictions: These restrictions reduce human exposure by reducing the consumption of potentially impacted tissues. Since zoning prohibits hunting on the Site and no fish-bearing surface water body is present on the Site, this restriction is effectively in-place.

Health and Safety Equipment: Using appropriate health and safety equipment and supplies is essential for individuals working on the Site during the cleanup action and Site development. When used properly, equipment such as protective clothing, boots, and a respirator can prevent exposure.

A.3.2 Monitoring

Monitoring can be used to prevent exposure by detecting contaminant migration. Early detection of the contaminant allows corrective action to be taken prior to exposure. At this Site, monitoring may be relevant to the following media:

- Groundwater;
- Air (during cleanup action only); and
- Soil.

Air monitoring is particularly useful during remedial construction because of the greater risk of exposure from dust. Verification sampling of the soil can be used during construction to verify that the contamination has been addressed.

Groundwater and surface water monitoring is useful in situations where there is uncertainty as to how a constituent might migrate to and in the aquifer, or in the surface water.

Since groundwater or surface water has not been impacted by lead and arsenic during the operation of the facility there is little chance that groundwater will be impacted following cleanup action. Groundwater and surface water monitoring may be required in association with stabilization or related to existing DNT-impacted groundwater contamination.

A.4 Containment

Containment uses physical barriers to either prevent direct exposure to the constituent or prevent migration of the constituent into the environment. Migration may be prevented by either preventing movement of the impacted medium or preventing a transport agent—such as water—from contacting the impacted medium. Containment technologies do not change the nature of the constituent but reduce risk by preventing exposure to the constituent.

Four containment technologies for soil are discussed below; cover, cap, liner and cap/cover.

A.4.1 Cover

Covers are characterized by a physical barrier between the impacted medium and the atmosphere. Usually, the purpose of a cover is to prevent or reduce contact between the impacted medium and precipitation. Covers also serve to prevent exposure to wind and to prevent direct contact by humans or animals.

Covers are used when there is extensive subsurface contamination that is difficult to remove or remediate in-place. Covers are often used over stabilized material or residues from other treatment technologies. Covers may also be used over soil with constituent concentrations below remediation levels, but still above cleanup levels, to prevent direct contact and further reduce residual risk.

Clean Soil Cover: A clean soil cover consists of the placement of imported clean soil on top of the soil to be covered. It prevents direct contact with the covered soil and provides a good substrate for vegetation. As vegetation will prevent erosion, little maintenance of the soil cover may be required. It is an effective low cost option when no leachable constituents of concern are present.

Re-vegetation: Although it can be used alone, re-vegetation is usually associated with some form of soil cap. The vegetative cover protects the cap from wind and rain erosion. It can also prevent direct contact with uncapped impacted soil during the cleanup action process and reduce windblown dust. Re-vegetation does not, however, prevent direct contact to plants or burrowing animals.

A.4.2 Cap

Engineered Cap (Synthetic Membrane, Clay, Asphalt, Asphalt Concrete, Portland Cement Concrete, Multimedia): Low permeability caps can be constructed from a variety of materials, or combinations of several materials. Materials that may be used in cap design, either individually or in combination, include synthetic polymer membranes, clay, asphalt, asphalt concrete, or Portland cement concrete. These materials are subject to damage so that engineered caps require long-term maintenance. Engineered caps are the most effective covers to reduce percolation of rain through the covered soil. Since lead and arsenic in low concentrations are not leachable, engineered caps have some limited use at the Site.

A.4.3 Liner

Liners are characterized by a physical barrier between the impacted medium and the underlying soil or groundwater. The main purpose of the liner is to reduce water movement from an impacted zone to clean zones. Usually, the impacted soil is placed in a prepared, lined basin and eventually capped. Liner materials include **synthetic membrane** and **clay** although often a combination of the two is used (**multimedia liner**) (EPA, 1985). Unless a nearby source of clay is available, clay is not usually economical. There is no ready source of clay near the Site. DNT is the only constituent at the Site that is leachable and it has been almost entirely removed during interim source removal. Consequently, a liner would have limited use as a containment technology. A lined basin may be considered for on-Site placement of stabilized concentrated fines but an engineered cap over the stabilized soil would prevent infiltration and leaching more cost effectively. Liners will not be retained for further analysis.

In Situ Liner can be created using **grout injection**. In this process, low permeability grout is injected in a grid pattern across the Site. The grout permeates the soil underlying the impacted zone creating a continuous layer of very low permeability material. The biggest advantage of this method is that the impacted soil does not have to be excavated. This can be important if the contamination extends to a great depth. Disadvantages include expense and ensuring that the grout layer is continuous. This method is not appropriate for the Site where most of the constituents are located in the upper foot of soil.

A.4.4 Cap/Cover

Cap/Cover is the combination of an engineered cap or liner and soil cover. It prevents direct contact with the covered soil and provides a good substrate for vegetation. As vegetation will prevent erosion, limited/little maintenance of the soil cover may be required. It is an effective low cost option when no leachable constituents of concern are present.

A.5 Dust Control

Dust control is typically important only during cleanup action (excavation, screening). There are two basic types of dust control: binding agents and barriers.

Water Spraying: This is the most common binding agent used for dust control. It is used on virtually all construction jobs. It has the disadvantage that it is temporary and requires frequent reapplication. Applied at the correct flow rate, the water will not infiltrate to the groundwater.

Dust Suppressants: Chemicals or binding agents such as liquid asphalt last longer. These have the disadvantages that they may be toxic and are more expensive than water. Biodegradable dust suppressants are available, such as wood fiber suspended in water. This material is sprayed over the surface, as for water, to form a protective crust, although it does not dry as quickly. Because the dust suppressant caps are typically thin, they are susceptible to cracking, especially under traffic loading.

Wind Fences: A wind fence is a barrier that is placed around the perimeter of the area to be protected. It deflects the wind from the susceptible area preventing it from entraining dust particles. Wind fences are useful when constant activity prevents covering of susceptible areas and the wind blows from a constant direction. These are unlikely conditions at the Site; therefore, this option will not be considered in further analyses.

Plastic Covers: Plastic covers are another form of barrier. When soil piles sit for long periods of time, they can be covered with plastic. Plastic covers are effective regardless of the direction the wind is blowing. Plastic covers are currently used on the soil stockpiles at the Site.

Vegetation: One type of permanent dust control is vegetation. Vegetation can work both as a binding agent and as a barrier. Plant roots bind soil particles to the surface at the same time that the plant above the ground reduces near-surface wind speeds. Site development is expected to include landscaping and vegetation. Hydro-seeding may be used to establish a grass-type vegetation after cleanup action and before landscaping. Since vegetation is already part of the Site development plan, it will not be carried into further analyses.

A.6 Removal

Removal is a rapid method to move the soil from the uncontrolled environment of the impacted site to a controlled treatment or disposal area. Except for *in situ* methods, removal is required for all remedial alternatives.

Removal technologies do not change the nature of the constituent but reduce risk when combined with treatment or disposal technologies.

Excavation of impacted soils can normally be accomplished with conventional construction equipment such as scrapers, backhoes, bulldozers, and front-end loaders. Some excavation is required for virtually all remedial alternatives except No Action. In some special situations, such as on steep slopes, or near buildings and utilities, special equipment may be necessary.

A.6.1 Excavation and Off-Site Disposal

Off-site disposal is a proven, effective remedial technology. Sites can be quickly and permanently cleaned up, although the nature and toxicity of the constituent is not changed. The main disadvantage of off-site disposal is the potential liability associated with mismanagement of the contained waste in the receiving landfill.

Hazardous Waste Landfill: Disposal in a hazardous waste landfill is a proven technology. This type of management is usually reserved for wastes that have been characterized as state dangerous or RCRA (federal) hazardous wastes based on their properties or characteristics or because they have been explicitly listed in state and federal hazardous waste regulations (e.g., Chapter 173-303 WAC and 40 CFR Parts 260 through 270). Thus the properties, characteristics, or constituents of these hazardous wastes warrant special, RCRA landfill disposal requirements.

The EPA Land Disposal Restrictions (LDRs) require that hazardous wastes be subjected to minimum levels of treatment and/or contain minimum concentrations of hazardous constituents before they, or residues from their treatment, can be land disposed of. Off-site land disposal of soils that are hazardous wastes may require treatment of concentrations that are above LDR concentrations.

Solid Waste Landfill: This technology involves disposal in a lined landfill with a leachate collection system. Solid waste landfills are the prime repository for municipal trash and garbage. Some solid waste landfills also accept industrial waste including problem waste.

Chapter 173-304 WAC defines problem wastes as "(a) soils removed during the cleanup of a remedial action site, or a dangerous waste site closure or other cleanup efforts and actions and which contains harmful substances but are not characterized dangerous wastes, or (b) dredge spoils..." Regulations that deal specifically with problem waste (PW) management and disposal have not yet been developed (as of March 1994). Disposal as a PW may be suitable for stabilized soil which passes the toxicity characteristic leaching procedure (TCLP) tests or for mixture of non-hazardous impacted soils with constituent concentrations above the Cleanup Standard.

Demolition Debris Landfill: Demolition debris landfills are unlined. Debris landfills have been used for debris disposal during interim source removal and additional disposal of non-hazardous debris is anticipated as part of future cleanup action. Disposal of the Site soils in this type of landfill would not be appropriate.

A.7 Immobilization

Immobilization is a response action designed to accomplish at least one of the following (EPA, 1986):

- Improve the handling and physical characteristics of the soil;
- Decrease the surface area available for the transfer of constituents from the soil; and/or
- Limit the solubility of the constituents in the soil.

Immobilization is often used in conjunction with disposal of material in a commercial landfill (EPA, 1985).

Immobilization encompasses two technologies: solidification and stabilization (or fixation). The emphasis of the first is to create a high strength material which will reduce the exposure to the impacted soil by direct contact. The second technology focuses on reducing the constituents mobility within the matrix. Those two technologies overlap as some solidification reagents also have a fixation effect and vice versa. Often, both effects are desired. Consequently, solidification and stabilization will be considered as one technology.

A.7.1 Solidification/Stabilization

Common solidification reagents include **Portland cement** and **silicate-based** materials like fly-ash and polysilicate mixtures. These reagents have been used for many years in road construction and also provide stabilization for certain metals. Portland cement is effective to fix lead, and arsenic has been successfully stabilized with a polysilicate mixture.

Arsenic chemistry is complex, involving a variety of valence states and ionic species, and both inorganic and organic species. Arsenic oxides and sulfides can be stabilized but not the organic species (contained in herbicides). The arsenic oxide (found in flue dust from non-ferrous smelting operations) is soluble in both acid and basic environments. Lead is soluble mostly in an acid environment. The range of pH in which both lead and arsenic oxide will be stabilized is narrow. The stabilization of arsenic oxide and lead-impacted soil is difficult.

Mix design for solidification must be determined by bench-scale testing with the actual Site soil.

Other, innovative techniques include **thermoplastic** solidification and **encapsulation**. In thermoplastic solidification, the soil is sealed in a matrix such as asphalt bitumen. This technique requires specialized equipment. Asphalt incorporation is a thermoplastic solidification method which is also a recycling process for the impacted soil. It can be applied only to soil passing TCLP tests and therefore is unlikely to be an option for most soils above the statistical action levels (SALs). Encapsulation uses an organic binder or resin to physically contain waste materials either by containing individual soil particles or a cluster of particles. The encapsulation processes are generally proprietary and expensive.

Cryogenic encapsulation is a temporary solidification process only. A large power supply is required to keep the ground frozen. No temporary solidification is required at the Site; therefore, this process will not be further analyzed.

One common method of fixation is to use **sorbents**, such as fly-ash or bentonite, to absorb free liquid and produce a solidified waste. Other additives can be used to chemically fix constituents by forming an insoluble precipitate or complex. Many proprietary mixes exist to fix various constituents. This technology is not applicable at the Site since the impacted soils do not contain free liquids.

Fixation can also be achieved *in situ* or *ex situ* by **surfactant fixation**, often a proprietary process. This technology utilizes the application of specific inorganic and organic reagents which readily percolate through the impacted soils. They reduce heavy metals to their lowest valence state and render them insoluble as stable organometallic complexes. The detoxified soils achieve the TCLP requirements and are no longer leachable. This technology has been demonstrated only for low metal concentrations (lead and cadmium: 10 to 15 mg/kg) and may require toxic amounts of surfactant at higher concentrations. This technology will not be retained for further analysis.

Surface Soil Fixation employs soil mixing and grinding with addition of a fixating agent to homogenize concentrations in the surficial soil and stabilize the metals. The homogenization action results in a reduction of isolated elevated concentrations in the surficial 6 inches of soil. The fixating agent may be a constituent modifying the pH of the soil thus lowering the leachability potential of the metal or a proprietary additive forming a chemical bond with the metal for stronger fixation. Proprietary additives for strong fixation may not be necessary since none of the TCLP results for arsenic were above the limit of 5 mg/L. Surface soil fixation could be applied to mitigate direct contact risk by aggregating the fines. The addition of cement can result in the formation of a granular material that could be used as a subgrade under areas such as parking lots.

In situ Vitrification (ISV) is a process whereby impacted soils are melted with a high electrical current and then allowed to cool to form a stable glass-like material. ISV is a patented process developed by Battelle Pacific Northwest Laboratory for the U.S. Department of Energy as an in-place stabilization technique (Hansen, 1988). At the high temperatures created (over 1,700 degrees Celsius), organic

material undergoes chemical change by pyrolysis (thermal destruction in the absence of oxygen). The products of pyrolysis rise to the surface as off-gases which must be collected, monitored, and treated. Inorganics are immobilized by chemical incorporation in the melt and solidified with the residual product. The residual ISV product offers 20 to 45 percent volume reduction, and excellent structural, weathering, and biotoxicity properties.

Full scale tests with ISV have been conducted on a variety of soil types (Fitzpatrick et al., 1986; Timmons, 1989). The full scale unit has four electrodes spaced about 18 feet apart. This results in a melt zone about 30 feet wide.

Buried metal in the soil can cause short-circuiting problems for the ISV process depending on the physical state of the objects. Fitzpatrick et al. (1986) states that soil with up to 5 percent metal, by weight, can be vitrified. In recent tests, soils with up to 15 percent metal, by weight, have been successfully melted (Timmons, 1989).

In situ vitrification is not an appropriate process for the Site since most of the metal contamination is distributed in the first foot of soil.

A.8 Treatment

Treatment technologies permanently reduce the toxicity and/or volume of the constituent or impacted material. The cleaned soil can then be returned to the site, disposed of as clean fill, or placed in a landfill. Treatment technologies for metals-impacted soils include recycling, and thermal and soil washing processes.

A.8.1 Recycling

Lead Smelter: Recycling lead-impacted soil to a smelter involves recovery of lead from the soil by the same process which extracts lead from ore. A minimum soil lead content of 10 percent by weight is expected to be required for acceptance by the smelter. The presence of other metal constituents may be problematic as they would volatilize, remain in the slag as a waste product, or impact the quality of the lead metal product.

Cement Kiln: Impacted soil could also be recycled to a cement kiln where the volatile metals would be removed in the off-gas and recovered in the baghouse, and the heavy metals incorporated into the cement at low concentrations. The soil would have to pass the TCLP tests before being accepted by the cement kiln. This is an unlikely option for Site soils.

A.8.2 Thermal Treatment

Thermal treatment does not destroy metals. Lighter metals will volatilize, heavy metals will remain in the soil. Important concerns are potential air emissions and the liability associated with the residuals.

In general, thermal treatments are characterized by high costs based on energy consumption.

Slagging with Off-Gas Treatment: This process is a two-stage, high temperature system. The temperature inside the reactor section is between 1,400 and 1,850°C. In the high-temperature reducing atmosphere, metals such as lead, arsenic, and cadmium are vaporized from the waste. Less volatile metals such as copper, nickel, and cobalt, if present in sufficient quantities, coalesce as a molten alloy phase. The remaining components of the waste, which may include metal oxides such as those of iron, melt in a molten slag.

Products from the reactor are passed to a slag separator. The process gases are drawn from the slag separator through the off-gas system where the vapors are post-combusted with ambient air and condensed as metal oxides. The gases are subsequently cooled, and the mixed metal oxide particulate is collected in a baghouse before discharge to the atmosphere. This process significantly reduces the

volume of impacted material. The metal oxide particulates and the slag are withdrawn from the reactor and recycled or disposed of according to their toxicity.

Fixed and transportable full-scale treatment units exist. Their maximum treatment rate is 2.5 tons per hour, which will not be adequate to treat all the impacted soils within a reasonable time frame. This process will not be retained for further analysis.

Thermal Desorption: As mercury is fairly volatile compared to other metals (boiling point 356.9°C), thermal desorption can be used to recover it from soil. The impacted soil is heated to the point where mercury begins to volatilize; the vapors are collected and treated to recover the mercury. This process is only applicable to mercury and would leave other metals in the soil. As only small amounts of mercury contaminated soils occur on the Site, this technology was not retained for further analysis.

Hydrogen Volatilization: Hydrogen volatilization is a process in which lead is recovered by high temperature distillation in hydrogen. It is an experimental technology demonstrated only in the laboratory and will not be retained for further analysis.

A.8.3 Physico-Chemical Separation

Physico-chemical separation removes the constituent from the medium with a combination of physical (scrubbing, classifying) and chemical processes (solvent extraction, solubilization).

Solvent or Chelant Extraction: Soil is placed in a tank with a solvent or chelant. The mixture is agitated, and the solvent or chelant is used to extract the constituent from the soil matrix. Clean soil is returned to the Site and the solvent or chelant is treated to remove the constituent and is recycled. Concentrated residues from the solvent/chelant recovery process are then further treated or disposed of. EDTA, citric acid, and other solvents and chelants have been used with various metals. Solvent/chelant extraction is site-specific and generally requires a pilot study prior to system design. It has the advantage of returning most of the soil, clean, to the Site.

Solvent/chelant extraction is generally done in a batch process, where a volume of soil is placed in a mixing tank in one batch, treated, and then removed. Each batch of soil may be washed more than once with fresh solvent.

In Situ Extraction: In this process, lagoons are constructed over the impacted area. Water is allowed to infiltrate through the impacted soil into the underlying groundwater. The groundwater is then extracted for treatment and recycled back to the lagoons. This is a very simple process that is most useful when groundwater contamination already exists. If not, there is a risk of not capturing all of the infiltrating water and causing a groundwater problem. Another disadvantage is that fine-grained soils can greatly slow the process. Because contamination at the Site is shallow and water is a poor solvent for metals, this technology was not retained for further analysis.

Acid or Base Extraction: Impacted soils are washed with an acid or base leaching solution to concentrate the metals in solution. Other chemicals can be added to facilitate metals solubilization. The washed soil is then separated from the leaching solution and the soil may require neutralization before being backfilled on the Site. The solution is treated to recover the metals, by precipitation, reverse osmosis, or ion exchange. Precipitation produces a sludge containing the metals which can be recycled or disposed of at a RCRA landfill. Selective ion exchange can recover individual metals but is only cost-effective for recovery of precious metals. Reverse osmosis produces a concentrated solution of metals which requires further treatment. Acid extraction has been demonstrated as effective for lead. Most arsenic chemical constituents are not removed by acid. Basic solutions are more effective. As for solvent or chelant extraction, acid/base extraction has the advantage of returning most of the soil, clean, to the Site.

Electrical Separation: Electrokinetic soil processing is an *in situ* semi-continuous process for the removal of heavy metals, radionuclides, and organic bases from fine-grained silty clays. The application of a low intensity, direct current applied across the impacted soil, results in removal of the constituents through mass transfer mechanisms of diffusion, and ion migration. The pollutants present in the soils are removed in cycles. One cycle will typically capture 75% to 95% of the original constituent and will require 2 to 3 months. Each cycle involves application of direct current, removal of the constituents at the cathodes in either soluble or precipitated forms, and replacement of the lost soil moisture.

This technology is not cost-effective in sands and gravels and therefore not applicable to the Site.

Screening: Screening is a common pretreatment process for other types of treatment since oversized particles cannot be processed by equipment associated with soil washing and thermal treatment methods. In this process, soil is fed into a wire mesh screen to remove oversized particles. Most metal constituents in soil are bound up in the finer fraction of soil particles so screening also reduces the volume of impacted soil by removing the larger particles which do not exceed the Site-specific remediation levels.

Screening can be a dry or wet process depending on the degree of separation sought. Dry screening will not remove all the fines from the cobbles/gravel, especially if the soil is moist. Its advantage is that water handling is avoided. Wet screening uses water spray to wash the fines off the gravel and improve the degree of separation. The wash water will be carried with the fines and may require treatment. Wet screening generally allows separation to a finer mesh than dry screening.

Classification: Classification is a group of water-based processes which typically uses mineral processing technology (jigs, spirals, flotation, hydrocyclones, attritioning). The process generates a clean soil fraction, an impacted sludge or cake consisting of soil fines, other concentration material, and process water. The waste and concentrates may require treatment prior to recycling. The sludge may be recycled to a lead smelter (if the lead is highly concentrated) or a cement kiln, or disposed of in a RCRA landfill. A pilot-scale test is necessary to determine the feasibility of this technology for a given soil. Classification has the advantage of returning a large fraction of the soil, clean, to the Site while not involving the handling and treatment of chemicals (solvent, acid, or base). Classification may be a more or less complex process depending on the concentration rate desired and the equipment required to achieve that concentration.

A.9 References for Appendix A

- Bhatty, M.S.Y., 1987. Fixation of metallic ions in Portland Cement. Superfund 1987: 140-145.
- EPA Risk Reduction Engineering Laboratory (RREL) Database, Version 4.0.
- EPA Superfund Innovative Technologies Evaluation (SITE) demonstrations.
- EPA Vendor Information System for Innovative Treatment Technologies (VISITT) Database, Version 2.0.
- EPA, 1983. "Project Summary, Mobile System for Extracting Spilled Hazardous Materials from Excavated Soils." USEPA, R. Scholz and J. Milanowski. EPA/600/52-83-100.
- EPA, 1985. "Handbook: Remedial Action at Waste Disposal Sites," Hazardous Waste Engineering Research Laboratory, Office of Research and Development, USEPA, Cincinnati, Ohio.
- EPA, 1986. "Handbook for Stabilization/Solidification of Hazardous Waste," EPA 540/2-86/001, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, USEPA, Cincinnati, Ohio.
- EPA, 1988. "Technology Screening Guide for Treatment of CERCLA Soils and Sludges." USEPA, Washington, D.C., September 1988.
- EPA, 1991a. "EPA's Mobile Volume Reduction Unit for Soil Washing." USEPA, H. Masters and B. Rubin. EPA/500/D-91/201.
- EPA, 1991b. "Superfund Engineering Issue: Treatment of Lead-Contaminated Soils." USEPA, Office of Solid Waste and Emergency Remedial Response, Washington, D.C., April 1991. EPA 540/2-91/009.
- EPA and U.S. Air Force, 1993. "Remediation Technologies Screening Matrix, Reference Guide." USEPA, Office of Solid Waste and Emergency Response Technology Innovation Office, Washington, D.C. 20460 and U.S. Air Force, Environics Directorate, Armstrong Laboratory, Tyndall Air Force Base, Florida 32403, July 1993. EPA 542-B-93-005.
- Fitzpatrick, V.F., C.L Timmerman, and J.L. Berelt, 1986. "*In Situ* Vitrification - A Candidate Process for *In Situ* Destruction of Hazardous Waste," Seventh Superfund Conference, Washington, D.C., December 1986.
- Hansen, J.E., 1988. Letter from Geosafe Corporation, Kirkland, Washington to Hart Crowser, dated June 25, 1988.
- Hart Crowser, 1992. Mercury/Lead Leaching Study, Area 39 Soils, Former DuPont Works Site, Dupont, Washington.
- Henderson, L., T. Delfino, M. Rafferty, T. Kimura, S. Takeshima, D. Lovell, and D. Yang, 1993. "*In Situ* Fixation of Arsenic and Heavy Metals in Soils." AIChE 1993 Summer National Meeting, Techniques for Solidification/Stabilization of Soils and Sludges, Seattle, Washington, July 1993.
- Timmons, D.M., 1989. "In Situ Vitrification of Wastes Contaminated with Mercury, Arsenic, Organochlorine Pesticides, and PCBs." Air & Waste Management International Symposium on Treatment of Contaminated Soils, Cincinnati, OH, February 1990.

APPENDIX B – OVERVIEW OF SOIL TESTING PROCEDURES AND DATA INTERPRETATION

B.1 Whole Soil Procedures

Sample Preparation: Upon receipt, the soil sample was coned and quartered, and blended and split to produce a more homogeneous head sample.

Stage Crushing: Throughout the course of this program, samples assayed for chemical constituents were crushed prior to analysis. The fines were separated out and the oversize was crushed again. The entire process was repeated until the desired particle size was achieved. This helped to ensure that a representative sample was assayed.

Sample Verification Testing: After sample preparation, three grab samples were collected. Each sample was analyzed for total lead. The TCLP was performed on a composite of the three samples, with leachate analysis for total lead. These analyses were performed on a rush or priority basis to check whether the lead sample collected was representative of the lead concentrations at the Site, based on the results of previous sampling events.

Moisture Content: The sample was air dried and the moisture content was reported as a percent weight loss. This provided an indication of how wet or sticky a soil was and how dry that soil can be made by stockpiling in a dry area. This information was useful for materials handling and technology selection.

Soil Bulk Density: This parameter, measured as kilograms soil per cubic meter, provided an exact conversion from volume to weight. Loose density was representative of soil in an excavated condition, while packed density was representative of *in situ* conditions. The sample for packed density measurement was not compressed, but was prepared by tapping the container so that the soil settled.

Soil Plasticity (Atterberg Limits): The liquid and plastic limits, and plasticity index are qualitative measurements indicating soil plasticity. This information provides an indication of how sticky the soil is, and how it deforms and flows (rheology). The information was used for identification and classification of fine-grained soil and clays. It was useful for materials handling, when choosing excavation and mixing equipment for implementation of treatment technologies.

Particle Size Distribution: Soil was divided into approximately nine size fractions ranging from cobbles/gravel, coarse to fine sands, and silt/clay by wet screening. The particle size distribution was used in determining the USDA soil classification. Each size fraction and the residual water were then analyzed for total lead. The weight and lead distributions were reviewed to determine which particle size fractions contained the lead and which fractions are "clean". This information was used to evaluate the effectiveness of soil washing and the quality of the wash water. Highly contaminated fractions may be further analyzed for lead species.

Standard USDA Soil Classification: The soil classification was determined from the soil particle size distribution, plasticity information, and visual observation. The various groupings of this classification system was devised by the ASTM committee to correlate in a general way with the geotechnical engineering behavior of soils. The classification was useful in understanding the behavior of the soil in materials handling and treatment processes.

RCRA Appendix IX Semivolatile Organic Compounds: This information was needed for regulatory purposes and constituent screening. Information on concentrations of semivolatile organic compounds is also important when evaluating treatment technologies, since they may interfere with performance or may be released as emissions. Samples were not assayed for volatile organic compounds, since many of the

sample homogenization and preparatory procedures permit volatilization. Additionally, samples were not assayed for pesticides, herbicides, PCBs, dioxins, and furans, since historical evidence and prior analyses do not indicate the presence of these constituents at the areas studied at the Site.

RCRA Appendix IX Inorganic Compounds: This information was needed for regulatory purposes and constituent screening. While this study was primarily concerned with lead-affected soils, the soils in the study contained other metals of regulatory concern. Treatment processes which concentrate lead or extract/leach lead in a particular soil fraction (soil washing) may also concentrate or extract other heavy metals.

Soluble Cations: Calcium, sodium, magnesium, and potassium were measured. These soluble cations can impact the system solubility and compete with heavy metal constituents for binding/bonding sites and anionic species. In general, cations are retained in soil types with higher clay content and surface area. Cations exhibit relatively low mobility in clay and silty clay soils and moderate to high mobility in sandy, loamy sand, and sandy loam soil.

Anions: Sulfide, sulfate, phosphate, carbonates, and bicarbonates are naturally occurring anions in soil which provide bonding and binding sites for heavy metals and soluble cations. In general, anions exhibit relatively low mobility in clay and silty clay soils and moderate to high mobility in other soil types.

Carbon Content: Total carbon is measured from the carbon dioxide evolved during combustion of a sample in an oxygen atmosphere. Inorganic or fixed carbon is determined by thermal gravimetric analysis (TGA). TGA involves heating a sample under an argon atmosphere at a known rate until first the moisture and then the volatile matter are driven out of the soil. Air is then introduced to oxidize any remaining material (fixed carbon) until only the ash remains. Inorganic (fixed) carbon is reported as a weight percent of the original sample. Organic carbon is determined to be the difference between the total and inorganic carbon. Organic carbon content is another indication of the soil's natural ability to bond and bind with constituents. Carbon content information was useful in evaluating both stabilization and soil washing technologies.

pH: This is a measure of the acidity or alkalinity of the soil. This information was used to determine whether the soil is RCRA hazardous because it exhibits the RCRA characteristic of corrosivity. Initial pH of the soil is a useful piece of information needed in calculating stabilization mix designs or in determining the effectiveness of acidic or basic soil washing.

Redox Potential: This is a measure of whether the soil is in an oxidizing or reducing state. Several elements can exist as part of the structure of soil minerals in more than one oxidation state. For example, manganese (Mn) can exist in soil as Mn^{+2} , Mn^{+3} , or $Mn^{+~}$. Arsenic (As) can exist as As^{+5} , or As^{+3} . The particular species which will be present depends upon the oxidation-reduction (i.e., redox) status of the soil.

Acid-Base Potential: This is a quantitative measure of the soil's buffering capacity. The amount of neutralizing bases present in the soil are reported as tons of calcium carbonate per 1,000 tons of soil. A positive number indicates that the soil is basic. Conversely, a negative number indicates that the soil is acidic. A close relationship exists between the total sulfur content of the soil and the net potential acidity. This information was useful in calculating stabilization mix designs or in determining the effectiveness of acidic or basic soil washing.

Generalized Acid Neutralization Capacity (GANC) and Reverse GANC: This test is a single-batch leaching procedure that utilizes a series of dried samples extracted for a 48-hour time period with an increasingly acidic leachant (or an increasingly basic leachant for the reverse GANC). A 20:1 liquid to solids ratio was used to duplicate the conditions of the TCLP. Equivalents of 2N acetic acid (or 2N sodium hydroxide per kilogram of dried solids) are plotted versus final solution pH. This information indicates the

buffering capacity of the material, and can be used to calculate stabilization mix designs or to determine the effectiveness of acidic or basic soil washing.

Metals with Acid Neutralization Capacity (MANC) and Reverse MANC: This test quantifies the concentration of a metal released when an amount of acetic acid (or sodium hydroxide) in equivalents is used to reduce (or increase) the pH of a solution. For each acidity (or alkalinity) value of the GANC (or reverse GANC), the concentration of a metal released was measured after a 48-hour time period. Equivalents of 2N acetic acid (or 2N sodium hydroxide) per kilogram of dried solids are plotted versus the concentration of a metal. While the GANC plot depicts the relationship between acid (or base) addition and pH (buffering capacity), the MANC plot depicts the relationship between acid (or base) addition and metal concentration (solubility). When the GANC and MANC are plotted on the same figure, the minimum solubility point for a metal is shown to correspond to a specific pH range. This information was used in calculating stabilization mix designs and in determining the effectiveness of acidic or basic soil washing (based on solubility of metals).

Toxicity Characteristic Leaching Procedure (TCLP): The TCLP is designed to determine the mobility of constituents in a waste. A solid waste exhibits the RCRA characteristic of toxicity if, using the TCLP test procedures, the extract from a representative sample of the waste contains any of a set list of constituents at or above certain concentrations. This information was required for regulatory classification, and proper handling and disposal of the waste soil. The TCLP and associated criterion may be used to set the remediation cleanup goals. The TCLP was used as a measure of the chemical performance of treatment technologies. Since the TCLP is an extremely aggressive acid equilibrium leaching procedure (20:1 liquid to solid ratio, small solid particle size, and 18-hour contact time), the TCLP results may also be used to calculate distribution coefficients, if the initial constituent concentrations are known.

Equilibrium Leaching Procedure (ELP): This is a leaching procedure that uses synthetic acid rain (SAR) to simulate weathering conditions at a site. It uses the same solid particle size and liquid to solid ratio (20:1) as the TCLP; however, it provides a more realistic leaching scenario since it uses 60% sulfuric acid/ 40% nitric acid SAR (instead of acetic acid) and a contact time of 96 hours (instead of 18 hours) to further ensure that the leaching is more realistic of site conditions and has been given time to achieve equilibrium. Lead assays are performed on both the leachate and solids to provide a complete mass balance for the calculation of distribution coefficients.

Surface Area Calculations: For each soil fraction or particle size range, the amount of surface area was calculated in square meters per kilogram. The smaller the particle size, the larger the surface area. Based on the weight distribution of the various soil fractions, the surface area distribution was calculated. In general, the majority of the surface area are associated with the fines or silt/clay fraction. The fine particles often exhibit adsorption, cation exchange capacity, and other binding and bonding properties.

B.2 Soil Fraction Procedures

FO39 List Metals: Treatment processes which concentrate lead or extract/ leach lead in a particular soil fraction (soil washing) may also concentrate or extract other heavy metals. This information was needed for constituent screening and regulatory purposes, to ensure proper handling and disposal of the soil.

Chloride: This is a naturally occurring inorganic anion which can affect the mobility of constituents. Chloride compounds are very soluble and therefore very mobile. This information was useful in determining the species and mobility of metals and, therefore, the impact to the environment.

Iron and Manganese: Heavy metals can bond and bind with iron-manganese oxide surfaces in the soil. This information was useful in determining the species and mobility of metals and, therefore, the impact to the environment.

Cation Exchange Capacity (CEC): The CEC is defined as the total amount of water soluble cations adsorbed by negative charges on a unit mass of soil. In general, the silt/clay fraction exhibits the highest CEC, since it has the most surface area. The adsorption process is reversible, and the equilibrium relationship can be expressed by K_d , the distribution coefficient. CEC is one component of the soil that is responsible for the soil's buffer capacity. Buffering mechanisms that involve metal cations in solution are affected by the extent of adsorption to cation exchange sites on soil particle surfaces. In arid regions, the accumulation of calcium, sodium, magnesium, and potassium salts may result in the saturation of a soil's cation exchange capacity with these cations. The tendency for these cations to produce hydroxide ions is the factor controlling the amount of hydrogen ions in the water phase of the soil (and thus the pH). Carbonate minerals (calcium carbonates, sodium carbonates, and magnesium carbonates) can buffer the hydrogen ion content (pH) of water in a soil system.

Sequential Extraction: This procedure is a wet chemical method in which a series of specific reagents is sequentially applied to a soil sample, and the lead content is measured in each extractant. Each reagent selectively removes lead that has been bound or adsorbed to the soil matrix in a specific way. The sequence of reagents is such that each reagent is more aggressive than the previous one. The results of this test indicate the species of lead present and the way in which the lead is bound to the soil. This information was valuable in determining impact to the environment and in evaluating treatment technologies.

Scanning Electron Microscopy (SEM): SEM is a sophisticated technique to determine constituent species by viewing the material under extremely high magnification. SEM analyzes individual soil particles and can identify both crystalline and amorphous structures. This information on constituent species was valuable in determining mobility and impact to the environment, and in evaluating treatment technologies.

X-Ray Fluorescence (XRF): This scan is performed to determine soil mineralogy. While the results are reported as compounds (mainly oxides and metals), the scan actually identifies major, minor, and trace elements (approximately 40). Results are reported as a weight percentage of the total sample. Carbon dioxide is also analyzed by a coulometric method, to aid in the material balance. The difference between the total weight of the soil and the weight percentage of minerals may be attributable to water. Information on soil mineralogy aids in the understanding of soil/ contaminant interactions including contaminant species, binding/bonding and mobility.